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Correlation of circumstellar SiO maser spot distribution with the stellar light curve

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Abstract. We have investigated the distributions of silicon monoxide (SiO) $v = 2$ and $v = 3$ $J = 1 \rightarrow 0$ masers around long-period variables (LPVs) in VLBI observations using the VLBI Exploration of Radio Astrometry (VERA) combined with the Nobeyama 45 m telescope. We find some examples of correlation of a maser spot distribution with the stellar light curve, which may provide a clue to elucidating the pumping mechanism of circumstellar SiO masers.

1. Introduction

There are three pumping models of circumstellar SiO masers: (1) stellar radiation pumping; (2) collisional pumping; (3) line overlapping [1, 2, 3]. The $v = 3$ $J = 1 \rightarrow 0$ SiO maser is expected as a unique probe to investigate the pumping mechanism of SiO molecules. According to the third model, the mid-infrared lines of H_2O molecules will pump SiO molecules from the $J = 0$ rotation level at lower vibration(v) levels to the $J = 1$ level at higher v-level, resulting in spatial correlation between the $v = 3$ and $v = 1/v = 2$ SiO masers. Multi-epoch VLBI mapping of these masers throughout different stellar light curve phase may enable us to discriminate a predominant pumping mechanism. In fact, it is suggested that the relative distributions of the $v = 2$ and $v = 3$ masers with respect to the central star may change with correlation with light curve [4].

2. Observations

We carried out VLBI observations of SiO $v = 2$ and $v = 3$ $J = 1 \rightarrow 0$ masers towards 12 LPVs (WX Psc, AP Lyn, U Ori, VY CMa, R Leo, RS Vir, W Hya, U Her, RU Her, V1111 Oph, V4120 Sgr, and T Cep) using four VERA 20 m telescopes and the 45 m telescope of Nobeyama Radio Observatory (NRO) on March 24–25 and May 21–22 in 2012.

3. Results and Discussion

The $v = 3$ maser emission was detected toward 5 stars. We succeeded in superimposition of $v = 2$ and $v = 3$ maser maps toward WX Psc, R Leo, W Hya (Fig.1), and T Cep (Fig.2). In T Cep, $v = 3$ masers well correlate with $v = 2$ masers within a few mas and 1 km s^{-1}, respectively. This result suggests that the H_2O–SiO line overlapping is predominant in T Cep. For T Cep and W Hya, we investigated correlation between the distributions of the two maser lines with

the stellar light curve. With the visible light curves provided by the American Association of Variable Star Observers (AAVSO), we find that good spatial correlation between the SiO $v = 2$ and $v = 3$ masers is found only at $\phi \sim 0.2$, when the near infrared radiation may be at a maximum [5, 6]. The sequence of the line overlapping mechanism is as follows: (1) the $\sim 8\mu$m emission increases at $\phi \sim 0.2$; (2) SiO molecules are excited from $v = 1$ $J = 0$ to $v = 2$ $J = 1$ and from $v = 2$ $J = 0$ to $v = 3$ $J = 1$ by $11_{6,6}$ $\nu 2{=}1 \rightarrow 12_{7,5}$ $\nu 2{=}0$ and $5_{0,5}$ $\nu 2{=}2 \rightarrow 6_{3,4}$ $\nu 2{=}1$, respectively; (3) the $v = 3$ masers increase around $v = 2$ masers. We speculate that the line overlapping mechanism may be predominant only at $\phi \sim 0.2$ while the collisional pumping may be predominant in other phases.

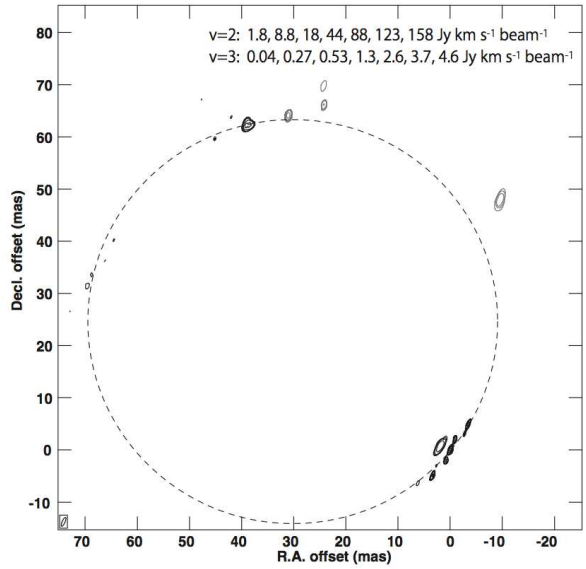

Figure 1. Composite map of $v = 2$ (black) and $v = 3$ (gray) maser lines toward W Hya. A dashed circle is drawn so as to fit to the $v = 2$ maser distribution. The $v = 3$ masers do not have any spatial correlation with $v = 2$. Interestingly, some of the $v = 3$ masers are located further away from the central star than the $v = 2$ masers.

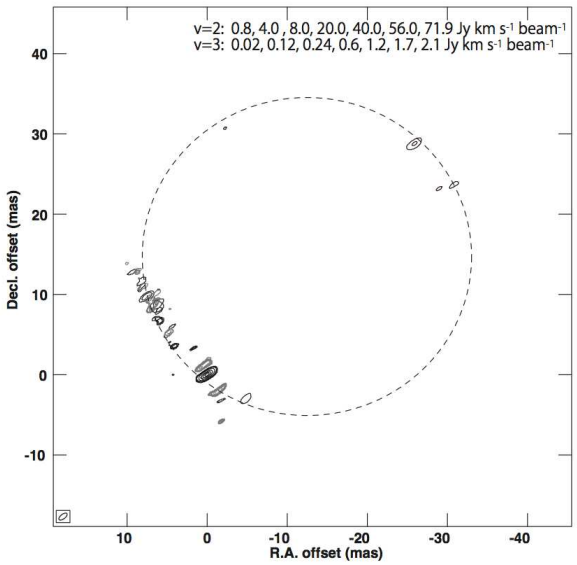

Figure 2. Same as Fig.1 but toward T Cep. These masers exhibit good correlation in position.

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